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13. ABSTRACT *(Maximum 200 words)*

The objective of this project is to create new ways of using Temporal Logic to support Dynamic Replanning of Air Tasking Plans. The formal axiomatic system for temporal logic that accommodates both points and intervals, Point-Interval Temporal Logic (PITL), has been implemented in the algorithm called TEMPER-2 (TEMPoral programmER). TEMPER 2 considers quantitative measures of time, namely time stamps and interval lengths. A new soilware architecture was developed to accommodate the new algorithm. CAESAR II/COA, a software system that transforms automatically influence nets into executable colored Petri nets, has been developed and tested. This integrated model of intelligence and planning tools is capable of generating effects-based courses of action. In addition, the use of occurrence graphs (reachability trees) permits the analysis and evaluation of alternative time phased sequences of actions. An approach for integrating command and control models with communications models has been developed. The objective is the development of an effective method for estimating the connection delays between tasks so that the performance of a C3 system which performs multiple tasks in a real-time distributed computer environment can be predicted. The approach taken is that of two state machines communicating with each other where each machine and their interactions are modeled using colored Petri nets.

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Project Title: **Time Sensitive Control of Air Combat Operations**

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ABSTRACT

The objective of this project is to create new ways of using Temporal Logic to support Dynamic Replanning of Air Tasking Plans. The formal axiomatic system for temporal logic that accommodates both points and intervals, Point-Interval Temporal Logic (PITL), has been implemented in the algorithm called TEMPER_2 (TEMPoral programmER). TEMPER 2 considers *quantitative* measures of time, namely time stamps and interval lengths. A new software architecture was developed to accommodate the new algorithm. CAESAR II/COA, a software system that transforms automatically influence nets into executable colored Petri nets, has been developed and tested. This integrated model of intelligence and planning tools is capable of generating effects-based courses of action. In addition, the use of occurrence graphs (reachability trees) permits the analysis and evaluation of alternative time phased sequences of actions. An approach for integrating command and control models with communications models has been developed. The objective is the development of an effective method for estimating the connection delays between tasks so that the performance of a C3 system which performs multiple tasks in a real-time distributed computer environment can be predicted. The approach taken is that of two state machines communicating with each other where each machine and their interactions are modeled using colored Petri nets.

2. OBJECTIVES AND STATEMENT OF WORK

The objective of this project, as described in the proposal is:

- Create new ways of using Temporal Logic to support Dynamic Replanning of Air Tasking Plans

The statement of work can be summarized in a set of tasks.

Task 1: Development of a Temporal Logic that addresses quantitative aspects of time and slacks to handle multiple timelines and multiple futures problems.

Task 2: Application of Temporal Logic to the problem of Dynamic Replanning to discriminate between four types of change.

Task 3: Integration of Point Interval Temporal Logic (PITL) into the Colored Petri net formalism.

Task 4: Development of a methodology to evaluate collaborative schemes.

Task 5: Document the results of the research in the form of theses, technical reports and journal papers. Present the results of the work in technical meetings. Submit progress and other reports to AFOSR in accordance with grant requirements.

There has been no change in the objective and the tasks. As indicated in last year's report, additional emphasis was placed on Task 4. Furthermore, the need to integrate the temporal aspects of command and control with the dynamic

3. STATUS OF EFFORT

The formal axiomatic system for temporal logic that accommodates both points and intervals, Point-Interval Temporal Logic (PITL), has been implemented in the algorithm called TEMPER_2 (TEMPoral programmER). TEMPER 2 considers *quantitative* measures of time, namely time stamps and interval lengths. A new software architecture was developed to accommodate the new algorithm. A Master's Thesis documenting the results is in the last stages of completion.

The Dynamic Replanning of Air Combat Operations was chosen in the past to illustrate the approach. However, the recent Air Force emphasis on effects-based planning motivated the expansion of the effort to include the Course of Action work in the model of the process. A doctoral thesis that addresses the integration of the intelligence function with the planning function by converting influence nets relating actions to effects into executable models (Colored Petri Nets) has been completed and is now under review.

A key problem in the modeling and simulation of the time sensitive aspects of air combat operations is the disjointness of C2 models and communications models. In C2 models depicting the decision making process and the actions taken, the effect of communications is modeled as a

delay. Conversely, in the communications models, message traffic is modeled as an external input. In order to analyze time sensitive operations, it is necessary to couple C2 models and communications models. This is not feasible with existing COTS software tools. A doctoral thesis addressing this subject is under way. The creation of interacting C2 models and communications models has been achieved and preliminary results have been obtained.

4. ACCOMPLISHMENTS/NEW FINDINGS

The first accomplishment this year was the development of a new software architecture for planning and replanning time-sensitive operations. At the center of the architecture is the algorithm TEMPER 2 that allows the sequencing and time phasing of actionable events to form a course of action. The algorithm allows the user to test whether new tasks can be inserted and assesses the effect of deleted or aborted tasks.

The second accomplishment was the development of CAESAR II/COA, a software system that transforms automatically influence nets into executable colored Petri nets. The latter can then be interconnected with executable planning models. The integrated model is capable of generating effects-based plans. In addition, the use of occurrence graphs (reachability trees) permits the analysis and evaluation of alternative time phased sequences of actions.

The third accomplishment is the formulation of the integrated command and control and communications problem. The objective is the development of an effective method for estimating the connection delays between tasks so that the performance of a C3 system which performs multiple tasks in a real-time distributed computer environment can be predicted. The approach taken is that of two state machines communicating with each other where each machine and their interactions are modeled using colored Petri nets.

5. PERSONNEL SUPPORTED

Faculty:
Prof. Alexander H. Levis (supported)
Graduate Students (Ph.D.)
Mr. Lee Wagenhals (supported)
Mr. Insub Shin (supported)
Graduate Students (MS)
Ms. Zainab Zaidi (supported; from 5/97 to 6/99)
Ms. Chun Ma (supported; from 8/97 to 8/99)
Mr. Yimeng Zhang (supported; since 8/98)

6. PUBLICATIONS

Two refereed encyclopedia articles on system architectures that present in part the methodology developed under this grant and that had been accepted for publication last year appeared this

year. The first paper on Temporal Programming appeared in May 1999, while the first paper on planning courses of action appeared in December, 1998.

A. H. Levis, "Systems Architectures," in *Systems Engineering and Management Handbook,* A. P. Sage and W. B. Rouse, Eds., Wiley, 1999

A. H. Levis, "Systems Architectures," in *Wiley Encyclopedia of Electrical and Electronic Engineering,* J. G. Webster, Ed., Wiley , 1999

A. K. Zaidi, "On Temporal Programming using Petri Nets," *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans,* Volume 29 Number 3, May 1999, pp. 245-254.

L. W. Wagenhals, I. Shin, and A. H. Levis, "Creating executable models of influence nets with colored Petri nets," Int'l J. on Software Tools for Technology Transfer (STTT), Vol. 2, No. 2, December 1998, pp. 168 – 181.

The count is **4.**

Two papers derived from the work on courses of action and from the integration of C2 and communications models have been accepted for presentation at the 2nd Workshop on the practical uses of Colored Petri nets in October 1999.

7. INTERACTIONS/TRANSITIONS 10/1/98 - 9/30/99

a. Participation in Conferences, Meetings:

1. Dr. Levis attended the 42nd Annual Meeting of the Human Factors and Ergonomics Society where he delivered a paper and served as a panelist.

2. Dr. Levis attended the 1998 IEEE Conference on Systems, Man and Cybernetics, where he delivered a paper.

3. Dr. Levis attended the 1999 International Command and Control Research and Technology Symposium in June 1999 at the Naval War College in Newport, RI.

b. Invited Presentations

1 Dr. Levis delivered a scheduled tutorial seminar on C4ISR Architectures at the Theater Warfare Center in Dahlgren, VA on July 30, 1999.

2. Dr. Levis and Mr. Wagenhals demonstrated the potential capability of CAESAR II tools and techniques (some of which were developed under this contract) for planning Information Warfare missions. The presentation was given at the Army's Land Information Warfare Agency (LIWA) in Ft. Belvoir, VA.

3. Mr. Wagenhals demonstrated the capability of CAESAR II to the Information Assurance program of DARPA.

c. Consultative and Advisory Functions

1. Dr. Levis and Mr. Wagenhals presented a four day course on C4ISR Architecture framework Implementation sponsored by ASD(C3I) and administered by the Armed Forces Communications Electronics Association (AFCEA) to the National Security Agency and to the Joint Interoperability Test Center of DISA in Ft. Huachuca, AZ.

2. Dr. Levis was reappointed to the Air Force Scientific Advisory Board in October, 1988. He served as a member of the AFRL Space Vehicles Directorate S&T Review panel; as a member of the Operational Test and Evaluation Advisory Group for AFOTEC, and chaired the Force Management panel of the 1999 SAB Summer Study on Technology Options to Leverage Aerospace Power in Operations other than Conventional War.

3. Dr. Levis was appointed by the Deputy Undersecretary of Defense for Science and Technology as a member of the three person US delegation to the Systems Concepts and Integration (SCI) Panel of the NATO Research and Technology Organization. He attended the Spring 99 meeting of the panel in Ankara, Turkey and the Fall 99 meeting in Italy.

d. Transitions:

1. The transition of the technology developed by the C3 Architecture Laboratory and embedded in CAESAR II (Computer Aided Evaluation of System Architectures) continued this year. The focus of the effort is the use of the CAESAR methodology and tools for assisting planners in developing and evaluating alternative offensive information warfare Courses of Action. The further development of the approach required the use of some results from Tasks 3 and 4. Specifically, the problem of time phasing the actionable events that constitute a course of action. Points of contact: Dwayne Allain (Rome Laboratory); Mike Kretzer (AFIWC).

8. NEW DISCOVERIES, INVENTIONS, PATENT DISCLOSURES:

None

9. HONORS/AWARDS

No new honors or awards this year.

Previous Lifetime Honors:

Prof. Levis is a Fellow of IEEE (1987) ;
Prof. Levis is a Fellow of AAAS (1991)
Exceptional Civilian Service Medal, Dept. of the Air Force (1994)